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13. ABSTRACT (Maximum 200 words) Research was carried out in the area of Reliability, Statistics and Probability. In Reliability, research was carried out in the area of repairable systems. In the area of Statistics, fundamental theoretical results were established concerning Markov chain Monte Carlo methods; such methods have found extremely wide range of applications. Combining work in the area of Probability, many useful results have been obtained in the area of Image Analysis.				
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1 MAIN TOPICS OF RESERACH CARRIED OUT UNDER THE GRANT

The later sections give more detailed summaries on the actual research reports and publications that ensued from this grant. In this section we will briefly list the areas of research. Research was carried out in the area of Reliability, Statistics and Probability. In Reliability research was carried out in the area of repairable systems. In the area of Statistics, fundamental theoretical results were established concerning Markov chain Monte Carlo methods; such methods have found extremely wide range of applications. Combining work in the area of Probability, many useful results have been obtained in the area of Image Analysis.

2 ACCOMPLISHMENTS DURING THE GRANT

2.1 Introduction

In this Section, we briefly describe the accomplishments in research during the grant. We give a list of the technical reports produced, followed by a list of published papers. In a later section we give a brief summary of the research findings. Most of this research work was also reported at professional meetings. Other sections list our professional activities and Ph D. degrees awarded during the grant.

2.2 Publications and Technical Reports under the Grant

2.2.1 List of Technical Reports Prepared under the Grant.

Mixed Limit Theorems for Pattern Analysis

by Ulf Grenander and Jayaram Sethuraman

February 1993

USARO Technical Report Number D-132

Easy-to-Apply Results for Establishing Convergence of Markov Chains in Bayesian Analysis

by Krishna B. Athreya, Hani Doss and Jayaram Sethuraman

February 1993

USARO Technical Report Number D-133

How Pooling failure Data May Reverse Increasing failure Rates

by John Gurland and Jayaram Sethuraman

November 1993

USARO Technical Report Number D-134

Nonparametric Estimation in a General Repair Model

by Crisanto A. Dorado, Myles Hollander and Jayaram Sethuraman

June 1995

USARO Tech. Report No. D-135.

Easily Verifiable Conditions for the Convergence of the Markov Chain Monte Carlo Method

by Jayaram Sethuraman

December 1995

USARO Technical Report number D-136

Bahadur slope of the t-statistic for contaminated normal

by Narasinga R. Chaganty and Jayaram Sethuraman

March 1996

USARO Technical Report number D-137

2.2.2 List of Publications under the Grant.

Singularity of Gaussian random fields

by T. V. Kurien and Jayaram Sethuraman

(1993) *Journal of Theoretical Probability*, 6 89-99.

Easy to Apply Results for Establishing Convergence of Markov Chains in Bayesian Analysis

by Krishna Athreya, Hani Doss and Jayaram Sethuraman

(1993) *Proceedings of the Thirty-Eighth Conference on the Design of Experiments in Army Research Development and Testing* 263-270.

Strong Large Deviation and Local Limit Theorems

by Narasinga Rao Chaganty and Jayaram Sethuraman

(1993) *Annals of Probability* 21 1671-1690.

A Mixed Limit Theorem for Stable Random Fields

by T. V. Kurien and Jayaram Sethuraman

(1993) *Journal of Multivariate Analysis*, 47 152-162.

A mixed limit theorem for stable random fields

by T. V. Kurien and **Jayaram Sethuraman**

(1993) *Journal of Multivariate Analysis* **47** 152–162.

Testing the Minimal Repair Model Assumption in an Imperfect Repair Model

by Myles Hollander and Brett Presnell and **Jayaram Sethuraman**

(1994) *Journal of the American Statistical Association* **89** 289–297.

The role of a group of modules in the failure of systems

by A. M. Abouammoh and Emad El-Neweihi and **Jayaram Sethuraman**

(1994) *Probability in the Engineering and Informational Sciences* **8** 89–101.

A constructive definition of Dirichlet priors

by **Jayaram Sethuraman**

(1994) *Statistica Sinica* **4** 639–650.

Mixed limit theorems for pattern analysis

by Ulf Grenander and **Jayaram Sethuraman**

(1994) *Journal of Multivariate Analysis* **51** 414–431.

Reversal of increasing failure rates when pooling failure data

by John Gurland and **Jayaram Sethuraman**

(1994) *Technometrics* **36** 416–418.

How Pooling Failure Rate Data may Reverse Increasing Failure Rates

by John Gurland and **Jayaram Sethuraman**

(1995) *Journal of the American Statistical Association* **90** 1416–1423.

2.3 Nontechnical summary of research carried out under the grant

In Technical Report No. **D-132**, limit theorems are derived for probability measures of random configurations over graphs which are used as prior distributions in pattern theory. For one-dimensional graphs, these limits can be viewed as distributions of certain stochastic processes, while in higher dimensions the limits will in some cases have to be interpreted as belonging to Schwartz distributions. Such limit distributions are easy to use in pattern analysis, and greatly reduce the computing effort required in comparison with stochastic relaxation methods.

The Markov chain simulation method has become a powerful computational method in Bayesian analysis. The success of this method depends on the convergence of the Markov chain to its stationary distribution. In Technical Report No. **D-133**, we give two carefully stated theorems, whose conditions are easy to verify, that establish this convergence. We

give versions of our conditions which are simpler to verify for the Markov chains that arises most commonly in Bayesian analysis.

Since mixtures of Exponential distributions (with constant failure rate) have the decreasing failure rate (DFR) property, as shown by Frank Proschan in the Sixties, it is not unexpected that mixtures of distributions which have a mildly increasing failure rate (IFR) also have this property. What is, perhaps, surprising is that mixtures of IFR distributions with rapidly increasing failure rate may also behave in this manner. Striking examples of such mixtures are presented in Technical Report No. **D-134**, and illustrated graphically. When it is suspected that the sample is based on pooled data, as often happens in practice, this phenomenon could be cause for concern.

The construction and analysis of repair models is an important area in reliability. A commonly used model is the minimal repair model. Under this model, repair restores the state of the system to its level prior to failure. In the eighties, Kijima introduced repair models that could be classified as "better-than-minimal". Under Kijima's models, the system, upon repair, is functionally the same as a working system of lesser age which has never experienced failure. In Technical Report Number **D-135**, we present a new approach to the modelling of better-than-minimal repair models. Using this approach, we construct a general repair model that contains Kijima's models as special cases. We also study the problem of estimating the distribution of the time to first failure of a system maintained by general repair. We make use of counting processes to show strong consistency of the estimator and prove results on weak convergence. Finally, we derive a Hall-Wellner type asymptotic confidence band for the estimator.

The Markov Chain Monte Carlo (MCMC) method, which is a special case of the Gibbs sampler, is a very powerful method to simulate from complicated distributions arising in many contexts, including image analysis, computational Bayesian analysis, and so on. Existing results that ensure that this method will converge involve conditions which are difficult to verify in practice, and most practitioners, convinced that their particular problem will not be pathological and give up verifying altogether. In Technical Report Number **D-136**, we give a new set of sufficient conditions which are easy to verify in most applications.

The robustness of the t -statistic, in contaminated normal models, has been studied exhaustively using the criterion of Pitman efficiency. In Technical Report Number **D-137** we derive the Bahadur slope of the t -statistic based on a random sample from contaminated normal distribution, using some results in large deviation theory. A table of the Bahadur slopes at various alternatives is given from which we can see that there is a region of adequately large Bahadur slope for small levels of contamination.

2.4 Professional activities during the period covered by the grant

Attended the annual meeting of the Florida Chapter of ASA at the University of West Florida, Pensacola, FL, February 26-27, 1993.

Gave a talk at the Departmental Colloquium in the Department of Statistics, University

of Gainesville, FL, April 6, 1993.

Attended the 25th Symposium on the Interface of Computer Science and Statistics at San Diego, CA, April 14-17, 1993.

Attended the Joint Annual Meeting of IMS/ASA in San Francisco, CA, August 8-13, 1993.

Presented an invited paper in the Thirty-Eighth Conference on the Design of Experiments in Army Research Development and Testing at Rice University, Houston, TX, October 20-22, 1993.

Attended the planning meeting for the Army Coordinating Committee Meeting for the Army Design of Experiments Workshop (to be held in October 1994) in Washington, DC February 3, 1994.

Attended the International Conference on HIV Sequence Variation and Statistical Methods at Ohio State University, Columbus OH, March 4-6, 1994.

Gave a talk in the departmental colloquium at the Department of Statistics, University of Chicago, Chicago, IL on April 4, 1994.

Gave a talk in the departmental colloquium at the Department of Statistics, University of Wisconsin, Madison, WI on April 5, 1994.

Participated in the Army Review meeting at Research Triangle Park, NC, April 25, 1994.

Participated in the Annual IMS/Bernoulli Society meeting held at Chapel Hill, NC June 20-24, 1994.

Participated in the Annual ASA meeting held at Toronto, Canada, August 14-18, 1994.

Panel discussant at the Thirty-Ninth Conference on the Design of Experiments in Army Research Development and Testing held at West Point, NY, October 18-21, 1994.

Gave an invited talk at the Annual TIMS/ORSA meeting held at Detroit, MI, October 23-25, 1994.

Invited participant at the Army Investment Strategy for the next 5 to 10 years meeting held at Orlando, FL, December 12-13, 1994.

Gave a talk at the meeting of the FL chapter of the ASA in Tallahassee, FL in February 1995.

Delivered the Ralph A. Bradley Lecture and after dinner banquet talk at the University

of Georgia, Athens Georgia on April 21, 1995.

Participated in the Army Conference on Applied Statistics held at Adelphi, MD, October 16-20, 1995.

Gave a talk in the departmental colloquium at the Indian Statistical Institute, Bangalore, July 1995.

Delivered an invited Platinum Jubilee Lecture in the Statistics Section of the 83rd Indian National Science Congress, held at Patiala, Punjab, India on January 5, 1996.

Presented a paper at the meeting of the FL Chapter of the ASA at Jacksonville in February 1996

2.5 Ph. D. Degrees Awarded

Crisanto Dorado On a General Repair Model for Repairable Systems, (1995) (dissertation directed by Jayaram Sethuraman and Myles Hollander).

2.6 Honors Received

Jayaram Sethuraman received a **NSF/ASA/NIST Senior Fellowship** 1994 to work with Statisticians at the National Institute of Standards and Technology in Gaithersburg, MD.

Jayaram Sethuraman received a **Fulbright Senior Research Scholar Award** from the Council for the International Exchange of Scholars and the Fulbright Foundation to teach and conduct research at the Indian Statistical Institute in Bangalore India from June 1995 till January 1996.

Jayaram Sethuraman was awarded a **Teaching Incentive Award** for excellence in teaching by Florida State University in December 1995.

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